Establishing evaluation index system for desertification of Keerqin sandy land with remote sensing data

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Abstract: Keerqin sand land is located in the transitional terrain between the Northeast Plain and Inner Mongolia (42°41'–45°15'N, 118°35'–123°30′ E) in Northeast China and it is seriously affected by desertification. According to the configuration and ecotope of the earth's surface, the coverage of vegetation, occupation ratio of bare sandy land and the soil texture were selected as evaluation indexes by using the field investigation data. The evaluation index system of Keerqin sandy desertification was established by using Remote Sensing data, and the occupation ratio of bare sandy land was obtained by mixed spectrum model. This index system is validated by the field investigation data and results indicate that it is suitable for the desertification evaluation of Keerqin.

Keyword: Sandy desertification; Evaluation index system; Remote sensing data; Keerqin sandy land; Inner Mongolia
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Introduction

The desertification index system is mainly used to evaluate current situation and trend of desertification, predict early changes of desertification, and to determine the causes of desertification (Gao and Wang 1998). Theoretically, it is not difficult to make a set of perfect desertification evaluation index systems. Since the1970s, many international organizations and national scholars have proposed the different evaluation index systems of desertification. Reining (1978) set up a desertification evaluation index system which is based on nature, living organisms and society. FAO/UNEP (1984) established a desertification evaluation index system which is based on different types of desertification, and Mouat (1992) put forward a desertification evaluation index system based on different scales, etc.. These index systems may involve decades or several hundred evaluation indexes, of which, however, only a few indexes are easy to be measured, sensitive to outside press, and applicable in practice (Yang and Zhang 2004). The evaluation index systems established by Chinese researchers also have the same problems mentioned above. For establishing a evaluation index system of desertification, the first important step is to choose some comprehensive and applicable evaluation indexes, thus avoiding the disconnect between the evaluation indexes and the process of evaluation. In this study we established an evaluation index system for desertification of Keerqin sandy land, which is easy to be calculated quantitatively by using Remote Sensing data.

Study area

The study is conducted in Keerqin sandy land, which is located in the transitional terrain between the Northeast Plain and Inner Mongolia (42°41'–45°15'N, 118°35'–123°30′ E) in Northeast China, with a total area of 423 000 km^2. The altitude of this area is in range of 180–650 m. The surface soil is poor and thin due to the arid climate, especially the strong wind and sparse precipitation in the spring. In addition, excessive grazing, deforestation, and irrational use of water resource have destroyed the fine coverage of vegetation and soil and further destructed the fragile ecological environment of Keerqin

Study method

Field investigation

One drawback for the existing evaluation index systems of the sandy desertification is lacking field investigation, which makes the results unpractical. In our study, we used the TM images of Naiman Banner (1:100000) on Sep. 13th, 1999 to determine the samples. On the basis of rough interpretation results of the TM images, 30 sample areas were selected for field investigation according to the different desertification types, land-used types and coverage of vegetation, and the central geographical coordinates of each sample area were input into GPS receiver, after then we used the navigation function of GPS receiver to navigate the sample areas one by one.

We selected 2–4 typical plots (1–100 m^2 in size) from each sample area, located the precise geographical coordinates of each plot, and investigated vegetation indexes, soil indexes, etc..

The investigative content includes the natural indicators such as numbers and sizes of plots, weather, geographical coordinates, desertification types, main plants, etc. and the desertification factors such as total coverage of vegetation, coverage of arbor, shrub and herb, biomass, soil types, soil moisture content, etc.. The oven drying method was adopted to measure the biomass of plant and soil moisture content. In total 892 effective data were obtained from the 30 sample areas.

Determination of evaluation indexes

To evaluate the expanding degree and changes of sandy desertification mainly depends on the changes of the earth's surface and ecological status (Zhang and Yang 2002). The basic principle for establishing an index system is to select the evaluation indexes that not only should be representative, reflect the sandy desertification degrees, and easy to study the macro-management

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of the dynamic change of the regional desertification (Kharin 1986), but also be apt to observation of earth's surface and be easily observed by using Remote Sensing and computer technology.

For judging the degree of sandy desertification, the evaluation indexes were chosen in accordance with the three respects: vegetation state (P), soil state (S) and the earth's surface state (E), which can reflect the sandy desertification state of the land from different sides (Fan 2002). The desertification degree (D) is calculated by the Equation (1):

$$D = P + S + E \tag{1}$$

By considering both the lately published achievements and the investigative results of Naiman Banner, we classify the desertification land of Naiman Banner into three types, and evaluation indexes for each desertification type are given (Table 1).

Table 1. Evaluation indexes of desertification for Naiman Banner, Inner Mongolia

Desertification types	Evaluation indexes
Desertification forest land	coverage of vegetation, occupation ratio of bare sandy land, soil texture
Desertification arable land	Situation of crop, soil texture, rank of soil nutrition
Desertification grassland	coverage of vegetation, occupation ratio of bare sandy land, soil texture

Calculation of the occupation ratio of the bare sandy land by Remote Sensing data

Remote Sensing obtains the image by dividing the continuous earth's surface into discontinuous pixels, every pixel corresponds to a certain ground-object, and size of the ground-object lies on the spatial resolution of the sensor. If each pixel represents a definite kind of the ground-object, the spectrum curve of the pixel can be determined by the ground-object. In fact, the signals obtained by the sensors with the certain spatial resolution are the mixed spectrum of two or more than two ground-objects. Especially in desert region, mixed spectrum is more obvious than in others, because of the low coverage of vegetation.

Mixed spectrum analysis is named mixed pixel classification. We regard the spectrum feature of pixel as mixed spectrum of different kinds of pure ground-objects (in the spectrum classification, they are called endmember) and calculate the proportion of each pure component in pixel

Linear mixed spectrum model

The most practical way to solve mixed spectrum is to assume it as a linear mixed problem. In RS, linear mixed models are generally formulated at the spectral level. It is assumed that the average reflectance in a spectral band is equal to the sum of the products of the area fractions of each component and their corresponding standard reflectance in that part of the spectrum plus an error term. The sum of the area fractions should be equal to 1; the standard reflectance can be derived either from spectral libraries, endmember determination, or directly from higher resolution data.

The basic assumption is that the spectra of some different ground-objects are combined together by linear approach, in other words, it is assumed that each component is independent. Based on the above assumption, we get this linear mixed spectrum model, namely Equation (2):

$$\rho(\lambda_i) = \sum_{j=1}^{m} F_j \rho_j(\lambda_i) + \varepsilon(\lambda_i) \tag{2}$$

where, $j = 1, 2, \ldots, m$th component; $i = 1, 2, \ldots, n$th spectrum channel; F_j is the area proportion of jth component that consists of the pixel; $\varepsilon(\lambda_i)$ is the error term of ith spectrum channel; ε is the sum of the error terms

provided:

$$\rho = \begin{bmatrix} \rho(\lambda_1) \\ \rho(\lambda_2 \\ \vdots \\ \rho(\lambda n) \end{bmatrix}, \quad f = \begin{bmatrix} F_1 \\ F_2 \\ \vdots \\ F_m \end{bmatrix}, \quad \varepsilon = \begin{bmatrix} \varepsilon(\lambda_1) \\ \varepsilon(\lambda_2) \\ \vdots \\ \varepsilon(\lambda_n) \end{bmatrix}$$

$$P = \begin{bmatrix} \rho_1(\lambda_1) & \rho_2(\lambda_1) & \cdots & \rho_m(\lambda_1) \\ \rho_1(\lambda_2) & \rho_2(\lambda_2) & \cdots & \rho_m(\lambda_2) \\ \vdots & \vdots & \vdots & \vdots \\ \rho_1(\lambda_n) & \rho_2(\lambda_n) & \cdots & \rho_m(\lambda_n) \end{bmatrix}$$

then, the Equation (2) can be written:

$$\rho = Pf + \varepsilon \tag{3}$$

If the spectrum of endmember is integrated, then the proportion coefficient F_j meets the restriction as Equation (4):

$$\sum_{j=1}^{m} Fj = 1 \tag{4}$$

Generally, the above restriction could not be met because it is hard to confirm whether the chosen spectrum of endmember has covered all the ground-object species in the whole investigative area or not. In addition, F_j is the area proportion of jth component that consists of the pixel, thus $F_j \geq 0$.

Linear mixed spectrum model is that given P and ρ, we find f.

The solution of the linear mixed spectrum model

(1) Least square method without constraints

Also because it is difficult to confirm whether the chosen spectrum of endmember has covered all the ground-object species in the whole investigative area, we directly do mixed pixel classification by Equation (3). That is,

$$\varepsilon = \rho - Pf \tag{5}$$

Construct function $\psi = \varepsilon^T \varepsilon$, then the first derivative of $\psi = \varepsilon^T \varepsilon$ with respect to f equals zero(Zhang and Wei 1992). That is,

$$P^T \rho - P^T Pf = 0 \tag{6}$$

Consequently

$$f = (P^T P)^{-1} P^T \rho \tag{7}$$

(2) Least square method with constraints

If the endmember is completely known, or it is partly given but its rough range is known, the sum of all proportions is assumed to equal to 1 when we estimate each component proportion of the mixed pixel. From Equations (3) and (4), it is easy to see:

$$\left.\begin{array}{l} \rho = Pf + \varepsilon \\ \sum_{j=1}^{m} F_j = 1 \end{array}\right\} \tag{8}$$

To find f in the Equation (8), construct function $\psi = \varepsilon^T \varepsilon - 2K(Af - 1)$, then the first derivative of $\psi = \varepsilon^T \varepsilon - 2K(Af - 1)$ with respect to f equals zero(Zhang and Wei 2000).

That is,

$$f = (N_{PP}^{-1} - N_{PP}^{-1} A^T N_{AA}^{-1} N_{PP}^{-1}) W + N_{PP}^{-1} A^T N_{AA}^{-1} \tag{9}$$

where, $N_{PP}^{-1} = P^T P$, $N_{AA}^{-1} = A N_{PP}^{-1} A^T$, $W = P^T \rho$, $\underset{1\times M}{A} = [1 \;\; 1 \;\; \cdots \;\; 1]$。

According to the above methods, we may get the occupation ratio of bare sandy land.

Establishment of the evaluation index system of sandy desertification

To avoid judging confusion caused by interlacing indexes, we adopt quantitive method to evaluate the desertification degree, that is, we use Deephi method to determine the weight of every index (X_i), grade every index and assign grade value (Y_{ij}), then, the degree of one desertification type can be calculated by Equation (10) (Fan 2002).

$$D = \sum_{i=1}^{n} X_i Y_{ij} \tag{10}$$

where, D is a degree index of a certain desertification land cell, n is the count of the evaluation indexes, X_i is the weight of ith evaluation index, Y_{ij} is the value of ith evaluation index in jth grade.

In order to adopt the survey data of the national desertification and achieve the interpretation of Remote Sensing images easily the indexes of the coverage of vegetation and the occupation ratio of bare sandy land are divided into 7 grades and the soil quality is divided into four grades. Different grade values of 1.0–4.5 were given to every grade. According to the past investigations, expert judgments, and the experimental results, we obtained the range of total values of desertification degree by calculating the weights of multiple factors, and divide desertification degree into four ranks: slight, medium, severe, extreme. After calculation of the total value of each desertification sample area by Equation (10), the optimal weight combinations were selected by taking the actual desertification degree of on-spot investigation as contrast. The occupation ratio of bare sandy land is 3.8, the soil texture is 2.6, and the coverage of vegetation is 3.6. Thus, a scientific and practical evaluation index system for monitoring sandy desertification is established (Table 2).

Evaluation of desertification of Naiman Banner

Table 3 showed the investigative results of the desertification land of Inner Mongolia Naiman Banner in 2004.

Table 2. Evaluation index system of sandy desertification of Naiman Banner, Inner Mongolia

Evaluation indexes	Weight	Value	1.0	1.5	2.0	2.5	3.0	3.5	4.5
Occupation ratio of bare sandy land (%)	3.8	Range	<10	10~20	21~30	31~40	41~50	51~70	>70
		Score	3.8	5.7	7.6	9.5	11.4	13.3	15.2
Coverage of Vegetation (%)	3.6	Range	>60	60~51	50~41	40~31	30~21	20~10	<10
		Score	3.6	5.4	7.2	9.0	10.8	12.6	14.4
Soil texture	2.6	Range	Loam		Sandy loam		Loamy sand		Sand
		Score	2.6		5.4		7.8		10.4
Desertification classes		Slight		Medium		Severe			Extreme
Range of total scores		10.0–20.0		20.1–27.0		27.1–34			34.1–40

Table 3. Land investigation of Naiman Banner, Inner Mongolia in 2004

Plot	Area (m^2)	Coverage of vegetation (%)	Soil texture	Land utilization situation
1	100	40	Sand	Sand
2	100	70	Sandy loam	Forest land
3	100	50	Loamy sand	Forest land
4	100	25	Sand	Sand
5	100	60	Loamy sand	Sand
6	100	95	Loamy sand	Grass land
7	100	10	Sand	Grass land
8	100	90	Loamy sand	Sand
9	100	20	Sand	Sand
10	100	65	Loamy sand	Sand

According to the investigative result in Table (3), we can get the index values from Table 2 and calculate desertification indexes of every sample by Equation (10) (Table 4).

Conclusions

The index system based on the field investigation is practical, available in this paper. Moreover, it is suitable for monitoring and evaluating quantitively desertification of Keerqin by using RS data.

At present, domestic scholars have tried to do some work on evaluating desertification and accumulated abundant experiences, however, there also need some improvement of the choosing of evaluation indexes. With the development of research, some different desertification evaluation index systems at different

scales should be established according to the needs of different levels. It is very useful for scientifically and accurately evaluating the current and trend of desertification in the future.

Table 4. Desertification indexes of Naiman Banner, Inner Mongolia

plot	Compositive indexes	Desertification degree
1	32.7	Severe
2	16.6	Slight
3	16.4	Slight
4	36.4	Extreme
5	22.7	Medium
6	15.2	Slight
7	40.0	Extreme
8	15.2	Slight
9	38.2	Extreme
10	20.9	Medium

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